UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

CLADDING PROCESS USING GAS METAL ARC WELDING AS A HEAT SOURCE AND 308L STAINLESS STEEL WIRE AS FEEDSTOCK

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ABSTRACT

Cladding technology in parts of manufacturing and repairing has been applied in many areas such as aerospace and automotive industries. One of the purposes of this technology is to prevent metallic surface from corrosion and wear. In order to reduce cost in tools and dies, layer-by-layer deposition technique in cladding process was formed by Gas Metal Arc Welding (GMAW) as a heat source. Stainless steel wire of 308L was used as a feedstock in which deposited on carbon steel substrate. The stainless steel wire was used to build the overlapped cladding for its known potential advantages. The 308L stainless steel clad was deposited directly by using a GMAW robotic welding to give a pore and crack free structure. The study was divided into two parts namely the investigation for stainless steel single bead clad and overlapped cladding (30% and 50% overlapped). The microstructure and microhardness behaviour of the 308L stainless steel structure was studied and solidification of 308L stainless steel during cladding process leads to dendritic formations which influence mechanical properties of the clad structure. Heat flow was studied to understand microstructure and microhardness variations of the clad material. The study also analysed corrosion behaviour of 308L stainless steel clad after cladding process. Design of Experiment (DOE) was employed in generated process parameter using Response Surface Methodology (RSM) method. Furthermore, the microstructural evolutions of 308L stainless steel cladding were investigated and the clad deposits were characterised by optical microscope, elemental mapping, Energy Dispersive X-ray (EDX), Vickers microhardness testing and electrochemical analysis. Results from the microstructural and microhardness properties was relate to the heat flow from the cladding process. The corrosion behaviour using Tafel extrapolation method was analysed in measuring the corrosion level of 308L stainless steel. Finding results indicated sample 12 (19.5V, 200 A and 35 cm/min) shows low corrosion rate behavior for 30% overlapped cladding.

ABSTRAK

Teknologi pelapisan dalam pembuatan dan pembaikan komponen telah diaplikasikan dalam pelbagai industri. Tujuan aplikasi pelapisan adalah untuk meningkatkan sifat permukaan logam daripada hakisan dan kehausan. Dalam usaha untuk mengurangkan kos bagi proses mengubah alat dan acuan, teknik lapisan demi lapisan dalam proses pelapisan telah dibuat dengan menggunakan Kimpalan Arka Logam Gas (GMAW) sebagai sumber haba. Dawai keluli tahan karat 308L telah digunakan sebagai bahan mentah dalam membaiki komponen yang rosak pada plat keluli karbon. Dawai keluli tahan karat menawarkan kelebihan yang berpotensi dan telah digunakan dalam kajian ini bagi membina pelapisan bertindih. Keluli tahan karat 308L telah dilapis terus dengan menggunakan robot Kimpalan Arka Logam Gas untuk memberi struktur yang tiada liang dan retak. Kajian penyelidikan dibahagikan kepada dua bahagian bagi mengkaji keluli tahan karat pelapisan tunggal dan pelapisan bertindih (30% dan 50% bertindih). Memahami mikrostruktur dan sifat kekerasan mikro untuk 308L struktur keluli tahan karat, pemejalan 308L keluli tahan karat semasa proses pelapisan membawa kepada pembentukan dendrit yang mempengaruhi sifat mekanikal struktur lapis. Aliran haba dianggap mengubah mikrostruktur dan mempertingkatkan kekerasan bahan. Kajian penyelidikan dijalankan dengan kakisan lapis keluli tahan karat 308L selepas proses pelapisan. Dalam tesis ini, Rekabentuk Ujikaji (DOE) telah digunakan dalam proses perolehan parameter menggunakan Kaedah Tindak Balas Permukaan (RSM). Di samping itu, evolusi mikrostruktur 308L keluli tahan karat pelapisan telah dikaji dan pelapisan dicirikan oleh mikroskop optik, pemetaan unsur, tenaga penyebaran x-ray, ujian kekerasan mikro Vickers dan analisa elektrokimia. Keputusan mikrostruktur dan kekerasan mikro bahan dihubungkait dengan aliran haba daripada proses pelapisan. Sifat kakisan menggunakan kaedah ekstrapolasi Tafel telah dikaji untuk mengukur kadar hakisan 308L keluli tahan karat. Keputusan kajian sampel 12 (19.5V, 200 A and 35 cm/min) menghasilkan kadar pengaratan yang rendah untuk 30% pelapisan bertindih.

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APPROVAL

This thesis is submitted to the Centre for Graduate Studies of UTeM as a partial fulfilment of the requirements for the Master of Science in Manufacturing Engineering. The member of the supervisory committee is as follow:

………………………………………

Supervisor

………………………………………

Co-supervisor

DECLARATION

I declare that this thesis entitle "Cladding Process Using Gas Metal Arc Welding as a Heat Source and 308L Stainless Steel Wire as Feedstock" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	………….................
Name	:	………………………
Date	:	………………………

DEDICATION

To my parents, for their care, patience and teaching.

To Shahzrin Sabri

For his support, understanding and concern.

To my brother and sister

Fellow friends, course mates and Universiti Teknikal Malaysia Melaka as a whole.

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LIST OF ABBREVIATIONS

Ar	-	Argon
ASTM	-	American Society for Testing and Materials
BM	-	Base metal
C	-	Carbon
CAD	-	Computer Aided Design
cm/min	-	Centimetre per minute
CO_2	-	Carbon dioxide
CR	-	Corrosion rate
Cr	-	Chromium
Cu	-	Copper
CZ	-	Clad zone
DMD	-	Direct metal deposition
DOE	-	Design of Experiment
DOP	-	Depth of penetration
DSPC	-	Direct shell production casting
E_{corr}	-	Voltage potential
EDX	-	Energy Dispersive X-ray
Fe	-	Ferum / iron
FGD	-	Flue Gas Desulfurization
FPI	-	Flourescent penetrant inspection
FZ	-	Fusion zone
GMAW/MIG		Gas metal arc welding/ metal inert gas
GTAW/TIG	-	Gas tungsten arc welding/ tungsten inert gas
HAZ	-	Heat affected zone
HCl	-	Hydrogen chloride acid
HLM	-	Hybrid layered manufacturing
I_{corr}	-	Current density

kJ/mm	-	Kilojoule/milimeter
mm/yr	-	Milimeter per year
Mn	-	Manganese
Mo	-	Molybdenum
NaCl	-	Natrium chloride
NC	-	Numerical codes
Ni	-	Nickel
OM	-	Optical microscope
P	-	Phosphorus
PAW	-	Plasma arc welding
PDAS	-	Primary dendrite arm spacing
RM	-	Rapid manufacturing
RP	-	Rapid prototyping
RSM	-	Research Surface Methodology
S	-	Sulfur
SDAS	-	Secondary dendrite arm spacing
Si	-	Silicon
SiC	-	Silicon carbide
SAW	-	Submerged arc welding
SEM	-	Scanning electron microscopy
TS	-	Traverse speed
XRD	-	X-ray diffraction

LIST OF SYMBOLS

A	-	Step length point
A	-	Thermal diffusivity (m^2s^{-1})
B	-	Interdendritic ferrite and austenite
Γ	-	Austenite
Γδ	-	Primary austenite with second phase ferrite
Δ	-	Ferrite
Δγ	-	Primary ferrite with second phase austenite
Η	-	Efficiency
Ξ	-	Distance from the moving source measured along the positive x-axis (ξ = x-vt)
Λ	-	Thermal conductivity ($Wm^{-1}K^{-1}$)
λ_1	-	PDAS
μ	-	Micron
ρ(T)	-	Density of the metal as the function of the temperature (g/mm^3)
C	-	Carbon
°C	-	Degree celcius
A	-	Arc current/current density
A	-	Area
C(T)	-	Specific heat of the metal as a function of temperature ($J/g^{-1}K^{-1}$)
EW	-	Equivalent weight
HV	-	Vickers hardness test
K	-	Overlapping ratio
k(T)	-	Thermal conductivity of the metal
M	-	Mole
N	-	Number of primary cells
Q	-	Rate of any internal heat generation (W/mm^3) / heat transfer
R	-	Rosenthal's radial distance from the heat source

T	-	Temperature of the weldment (K)
T	-	Time
V	-	Velocity
V	-	Arc voltage/voltage potential
V_x, V_y, V_z		Components of velocity
W	-	Watts
W	-	Width of single clad track (mm)
wt%	-	Weight percentage
X	-	Overlapping step length (mm)
X	-	Coordinate in the direction of welding
Y	-	Coordinate transverse to the welding direction
Z	-	Coordinate normal to weldment surface

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CHAPTER 1

INTRODUCTION

1.0 Background Study

Layer-by-layer process is one of the techniques used to fabricate a thin layer of high resistant material onto substrate. Akula *et. al.* (2006) used this technique by applying hybrid layered manufacturing. In addition, the similar technique has been developed to cover the required area of the substrate called cladding. Komvopoulos *et. al.* (1990) was claimed that the added material is fused onto the substrate which creates different metallurgical properties after a cladding process. As the process partially melts the added material onto the substrate, it creates a very thin layer to attain a metallurgical bonding with minimal dilution. The added material sustains the original properties of coating material once melted with the substrate.

At present, most of the cladding process is performed by using laser as a heat source and either powder or wire is used as a feedstock. For example, Leunda *et.al.* (2011) was used vanadium carbide tool steel powders for die repair while Cottam *et. al.* (2011) was used titanium alloys powder in repairing aircraft components. Meanwhile, Palani *et. al.* (2006) use wire as an added material in cladding stainless steel (SS). The cladding studies have shown the properties of microhardness increased at the cladded material.

Carbon steel components used as substrate are exposed to wear due to several times of services. Anjos *et. al.* (1997) states that carbon steel tends to corrode and damage during a long exposure in seawater. The layer-by-layer deposit is applied to repair the damaged parts of the carbon steel. Amado *et. al.* (2011) and Anjos *et. al.* (1997) repairs the damaged parts using layer-by-layer techniques. Therefore, austenitic 308L SS is used as the added material onto the carbon steel substrate in this focused research. In order to prevent carbon steel from corrosion in many industrial applications (Anjos *et. al.*, 1997), SS is commonly used as clad material (Palani *et. al.*, 2006).

Currently, cladding process has used quite a number of different techniques such as gas tungsten arc welding (GTAW), submerged arc welding (SAW), plasma arc welding (PAW) and gas metal arc welding (GMAW). In order to attract the interest of manufacturing industries, the GMAW was used as the heat source for this research study. The study of cladding process using GMAW was investigated using SS wire as the feedstock. The study was carried out by the automatic feeding of a continuous consumable electrode and robot welding.

The cladding process is an addition of material based on the rapid prototyping (RP) technology. Akula *et. al.* (2006) claim that the shape and dimensions of the clad bead are very important in the use of 3D deposit as an RP system for the layer manufacturing processes. Furthermore, by the use of arc cladding process, it is possible to deposit different material between 308L SS on carbon steel substrate (Anjos *et. al*., 1997 and Hussein *et. al.*, 2011). In order to understand the cladding process using the automated robotic GMAW, the 308L SS wire was deposited layer-by-layer on carbon steel substrate. This process would improve the understanding of microstructural evolution and microhardness of material due to the cladding process.

1.1 Problem Statement

At present, high corrosion resistance and good performance of materials are essential for a long term reliability service in manufacturing environment. However, a part has a certain life time before it is damaged. Fabricating new part to replace the damaged part incur cost. Thus, repair was a better option. GMAW is one of the alternatives used to repair the damaged parts as it is more economical for repairing purposes (Sreeraj *et. al*., 2013). Extensive research has been carried out by researchers on the cladding process using GMAW. The common filler materials used were titanium (Carvalho *et. al*., 2011), stellite (Madadi *et. al*., 2009 and Gupta *et. al*., 2010) and nickel (Gupta *et. al*., 2011). However, the cost of those filler materials is not economical for bulk repairing process. SS wire is one of the alternatives used as it is more economical compared to other filler materials. However, there is a lack of study on the effect of GMAW cladding process using 308L SS wire. The main aim of this research, then, is to study the effect of GMAW cladding using 308L SS wire on the mechanical properties and corrosion resistance of the cladded metal. The 308L SS is better for high temperature application and better creep resistance onto carbon steel substrate (Vitek *et. al*., 1992 and Lincoln, 2010).

1.2 Objectives

The overall aim of this research is to get an insight of the process characteristics in an attempt to understand the property, structure and process interaction associated with the shape metal deposition using GMAW as the heat source on a metal. The objectives of the research are to:

i. Study on the stainless steel used can be cladded directly by using gas metal arc welding (GMAW) as the heat source to give a pore and crack free structure.
ii. Analyse the effect of process parameters on microstructural evolution and mechanical behavior of the cladding material.
iii. Evaluate microstructural evolution and mechanical behavior with the heat flow during the cladding process.
iv. Evaluate the corrosion behavior of the cladded substrate.

1.3 Scope of the Study

This research focused primarily was used GMAW as a heat source on improving properties of 308L SS onto carbon steel substrate using cladding process. The variables parameter evaluated were arc voltage, arc current and traverse speed. The experimental were carried out using DOE by RSM method.

Microhardness properties of clad were examined using Vickers microhardness in accordance with ASTM E92. For microstructure observation, optical microscope was used. A sample preparation for microstructural evolution was based on ASTM E3-01. While other aspect such as clad dimension was measured. Fusion zone (FZ), heat affected zone (HAZ), depth of penetration (DOP) and heat flow of the cladding process was simulated using Smartweld software.

The general corrosion test was included using a typical test method known as electrochemical testing (Tafel). A comparison of the corrosion behaviour of variables parameter used (arc voltage, arc current and traverse speed) and heat input during cladding was included to prove that 308L SS can prevent and improve the corrosion resistant onto carbon steel substrate using GMAW. The mechanical properties caused by the corrosion were not covered in this study.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter reviews techniques to overcome problems such as resistance against wear and corrosion besides several thermal surface treatments that are currently available. Cladding is widely used to improve the surface properties of metallic parts. Various industries use cladding process to enhance material surface properties from corrosion and wear, repair worn parts and form near net shaped structures (Penn, 2008). Lim *et. al.* (2008) state that the cladding process develops new properties of material as well as improves damaged surface. In addition, Pinkerton *et. al.* (2008) also states that the cladding of SS and superalloy materials onto low alloy substrates has a potential for industrial application when a good corrosion or wear resistance is required. The arc fusion processes such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), gas tungsten arc welding (GTAW) and plasma arc welding (PAW) are widely used for the cladding operations.. This is supported by Schneider's (1998) study whereby the flame spraying, plasma spraying and arc welding are established techniques for cladding. In the study of cladding using GMAW as heat source and SS wire as feedstock, the cladding process comprises a formation of a new surface layer made up of 308L SS on top of corrosive such as carbon steel substrate. The new surface layer and properties are formed during heating and cooling section during layer-by-layer cladding process occurred.